Overview

The nu-ball array is designed as a high efficiency hybrid spectrometer with both Ge and LaBr3 detectors providing excellent resolution Ge (for high selectivity) and excellent timing resolution LaBr3 (for fast timing possibilities). The detectors will cover nearly $4\pi$ of solid angle. The Germanium part will consist of 24 clover detectors from the gammapool, and 10 or more coaxial detectors. The LaBr3 part will consist of up to 30 LaBr3 detectors most of which will be on loan from the FATIMA collaboration. The total photopeak efficiency of the device in its standard configuration is expected to be 8% at 1 MeV and 25% at 200 keV. It will be installed in the spectroscopy cave (420) and will be able to use all the available beams of the IPN tandem accelerator. It can also be coupled to the LICORNE directional neutron source permitting precision spectroscopy of fast neutron induced reactions.

Geometry and detector configurations

The nu-ball geometry is based around a modified version of the Jurogam II frame with a backbone of 24 clover detectors and their BGO shields. The standard configuration will have an additional 10 coaxial Ge detectors coupled to up to two rings of 10 and 6 and one ring of 10 conical LaBr3 detectors, covering the maximum available solid angle (see figure 1).

![Figure 1: GEANT4 modelisation of the future nu-ball array. The left picture shows nu-ball from backward angles and the right picture shows nu-ball from downstream.](image)

However, some flexibility is possible and changes can be made in the total Ge/LaBr3 ratio by replacing coaxial detectors with LaBr3 for example if it is needed for a particular experiment. The right picture in figure 1 shows such a configuration maximizing the LaBr3 photopeak efficiency (1.5% at 1 MeV). Efficiency has been calculated by full Geant IV simulations. Figure 2 shows the results of the calculations. A photo-peak efficiency of 8% at 1 MeV (and 25% at 200 keV) can be achieved.
Furthermore, the use of Compton suppression and add-back (in clovers only) can lead to a 46% of peak-to-total ratio\(^1\).

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<tr>
<th>Efficiency for nu-ball</th>
<th>Peak-to-Total for nu-ball</th>
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Figure 2: GEANT4 calculation of photo-peak efficiency and peak-to-total ratio for the nu-ball array. On the left, the red curve corresponds to an independent treatment for each crystal, the blue curve corresponds to the use of the add-back in the clovers. On the right, black curve represents the results for an independent treatment of the crystals, the red curve is the same with Compton suppression for clovers and co-axial detectors. The green curve corresponds to add-back in the clovers without Compton suppression. Finally, the blue curve corresponds to the use of Compton suppression and add-back.

Ancillary devices and neutron beams

It is foreseen that the nu-ball array will function with other ancillary devices which will provide some unique physics opportunities at the ALTO facility during the nu-ball experimental campaign.

\(^1\) Peak-to-total ratio has been defined as the number of counts in the full energy peak divided by the total number of counts in the spectrum.
1) The LICORNE neutron source
The nu-ball geometry allows coupling with the LICORNE directional beams, where neutrons of between 0.5 and 4 MeV in energy can be directed through the spectrometer onto thick targets (grams of target material) to perform precision spectroscopy of neutron induced reactions. Cone kinematics will be restricted to no greater than 25 degrees to prevent detectors being directly irradiated by neutrons. Fluxes of up to $10^7$ n/cm²/s will be possible in white source mode (broad energy distribution) and typically $10^6$ n/cm²/s in quasi monoenergetic mode (two neutron groups with a FWHM of typically 300 keV. This will allow some interesting new possibilities (e.g. population and study of fission isomers via $(n,n')$ reactions).

2) The OOPS plunger system
Lifetimes over complimentary ranges can be measured from a few ps to a few ns with a combination of the nu-ball fast timing capabilities, the OOPS plunger recoil distance device and the excellent beam pulsation available at the IPN tandem. This powerful combination will offer some new and interesting possibilities to study nuclear moments.

3) PARIS detector clusters
Up to 4 clusters of high efficiency phoswitches detectors will be available to couple to nu-ball at forward angles for detection of very high energy gamma rays with reasonable efficiency. This will allow a combination of Ge selectivity and high energy gamma detection, necessary for some unique types of experiments.

Nu-ball Digital DAQ: Extra selectivity from Calorimetry and Precision Event Timing
The nu-ball electronics will be fully digital using around 140 channels of the FASTER system developed at LPC Caen. The anti-Compton suppression will be performed by digitization of the BGO signals. This digitization also permits Calorimetry to be performed if the Clover collimators are removed giving sum-energy and multiplicity signals on an event-by-event basis for an additional selectivity, despite the high event rates anticipated in the BGO. Additional event selectivity will also be possible using the fast timing of LaBr3 detectors in coincidence with the beam buncher system to separate gamma rays from an event along the time axis. The minimum time resolution of the buncher system is currently 1.5 ns, but improvements may be possible down to 0.5 ns for the nu-ball campaign (although this improvement is not guaranteed).